Deposition of Wear and Corrosion Resistant Coatings onto Landing Gear Components Via Directed Vapor Deposition

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Directed Vapor Technologies International, Inc.

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Outline

- Directed Vapor Deposition: Background / Attributes
- Non Line-of-sight Coating Application onto Tubular Shapes
- Wear resistant DVD coatings for Cr Replacement
- Corrosion resistant DVD coatings for Cd Replacement
- Production Scale DVD Equipment

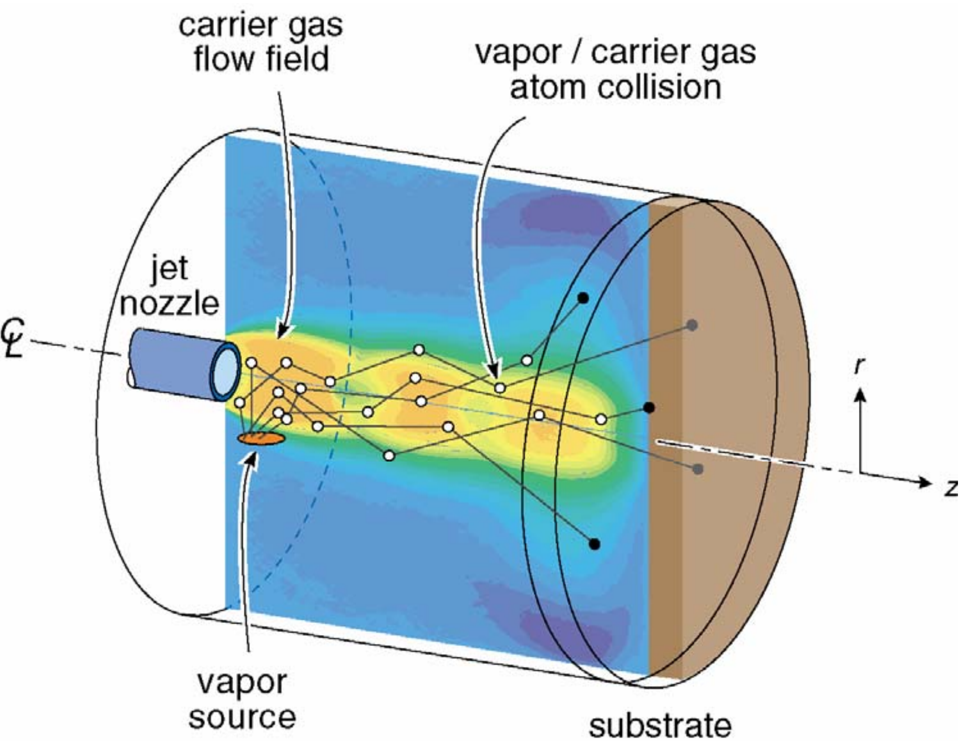
Acknowledgement:
Air Force SBIR Program; Craig Shaw and Ryan Josephson Hill AFB

Subcontractors: Battelle and Luna Innovations

*Electron Beam – Directed Vapor Deposition**

Concept

gas phase scattering of vapor (by collisions with background gas) enables the flux to be collimated

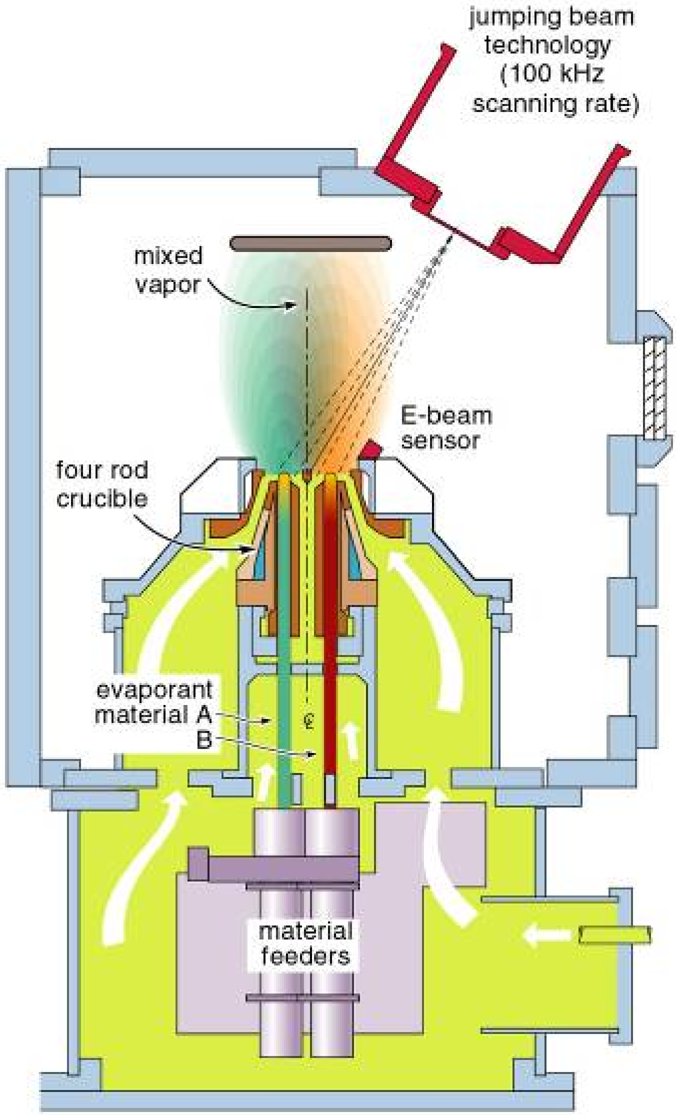


*J.F. Groves and H.N.G. Wadley, Composites B, **28B**, 57 (1997).

Rationale for DVD:

- increase deposition efficiency of EB-PVD process
- increase deposition rate
- non-line-of-sight coating
- soft vacuum – ease of use
- composition and morphology control

Directed Vapor Deposition



"Directed Vapor Deposition," J.F. Groves, G. Mattausch, H. Morgner, D.D. Hass and H.N.G. Wadley, Surface Engineering, 16(6), 461- 464 (2000)

Nozzle axis in-line
with the source

Focused vapor
high deposition efficiency

High deposition rates

Short pump down time

High pressure (0.1 – 1 Torr)
deposition and plasma activation
for morphology control

Multisource evaporation (at least 4 rod)
for composition control
(high speed
(100kHz) beam scanning)

Electron Beam – Directed Vapor Deposition

Combines four process technologies:

- advanced electron beam evaporation
- low-vacuum, flowing-gas vapor transport
- gas and vapor plasma ionization
- static or pulsed substrate biasing (0 - ±300V)

Applications:

- Thermal Barrier Coatings
- Cr and Cd replacement coating for aircraft landing gear
- Superconductivity Coatings
- Medical Device Coatings
- Lithium Ion Batteries
- Wire / Fiber Coatings

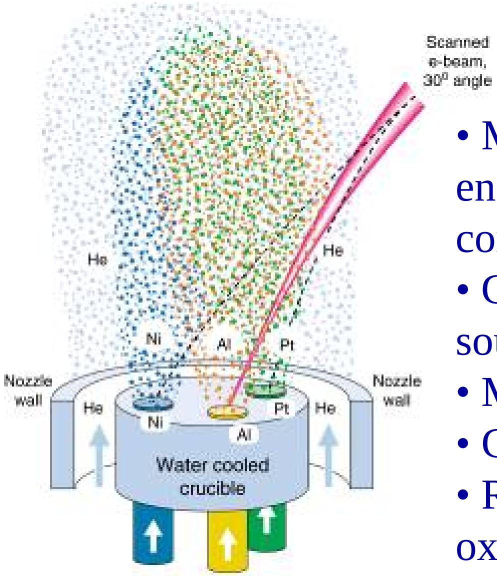
- Short pumpdown times (10 to 15 seconds)
- Small footprint
- Automated controls
- Easy to maintain vacuum

Electron Beam – Directed Vapor Deposition

Deposition Rate and Efficiency

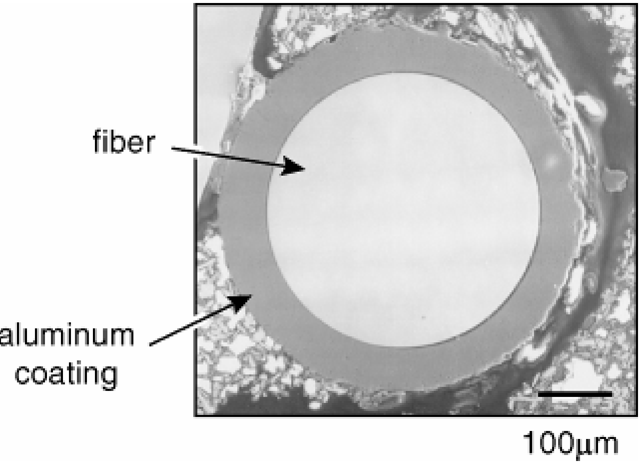
- Supersonic gas jet focuses vapor flux onto substrate
- Materials utilization efficiencies approaching 80%
- Deposition rates >80 µm/min.

Compositional Control



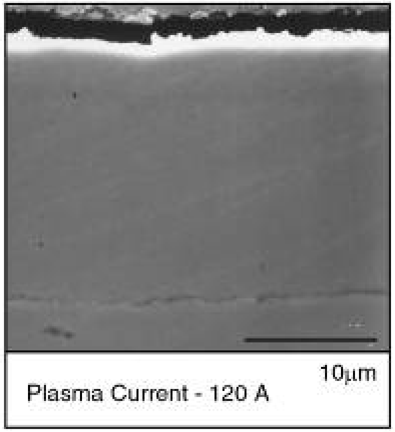
- Multi-source evaporation enables precise composition control
- Gas jet controls degree of source intermixing
- Multilayer coatings
- Combinatorial synthesis
- Reactive deposition of oxides and nitrides

Non Line-of-Sight Deposition



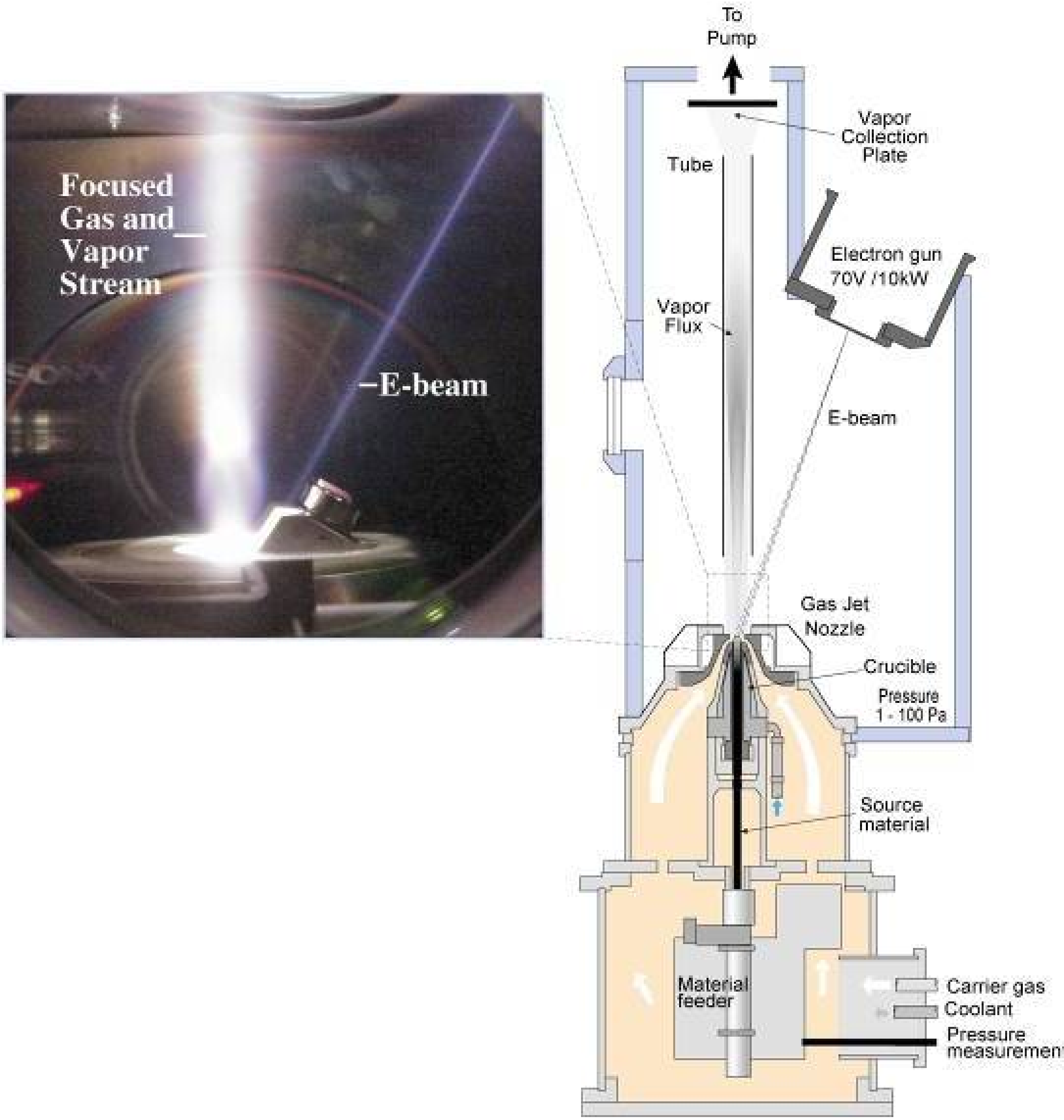
- Vapor phase collisions between vapor and gas jet atoms enable NLOS deposition

Microstructural Control



- Dense and porous coatings
- Plasma activation for dense layers

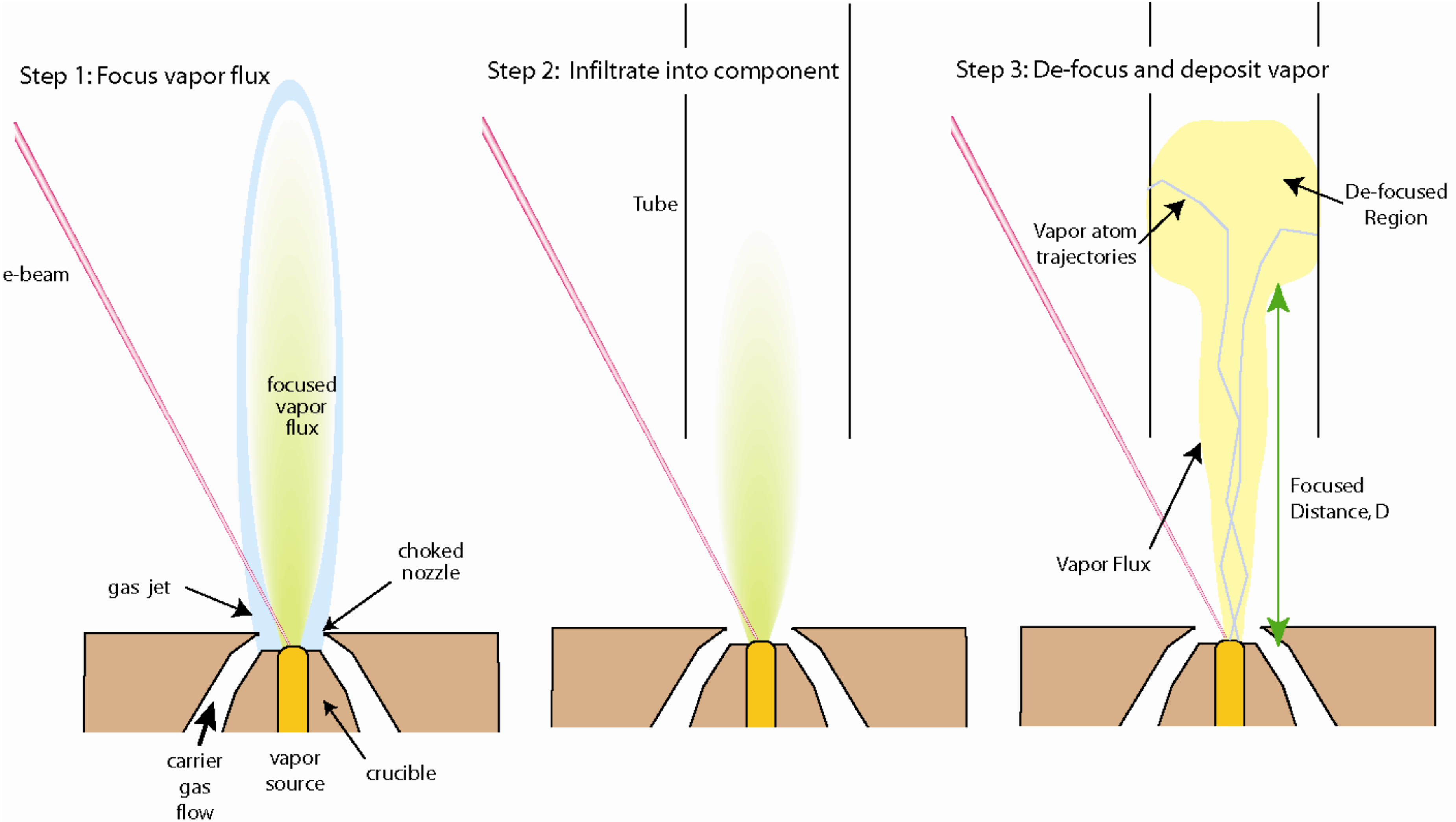
Landing Gear Coating (NLOS)



NLOS Deposition Approach

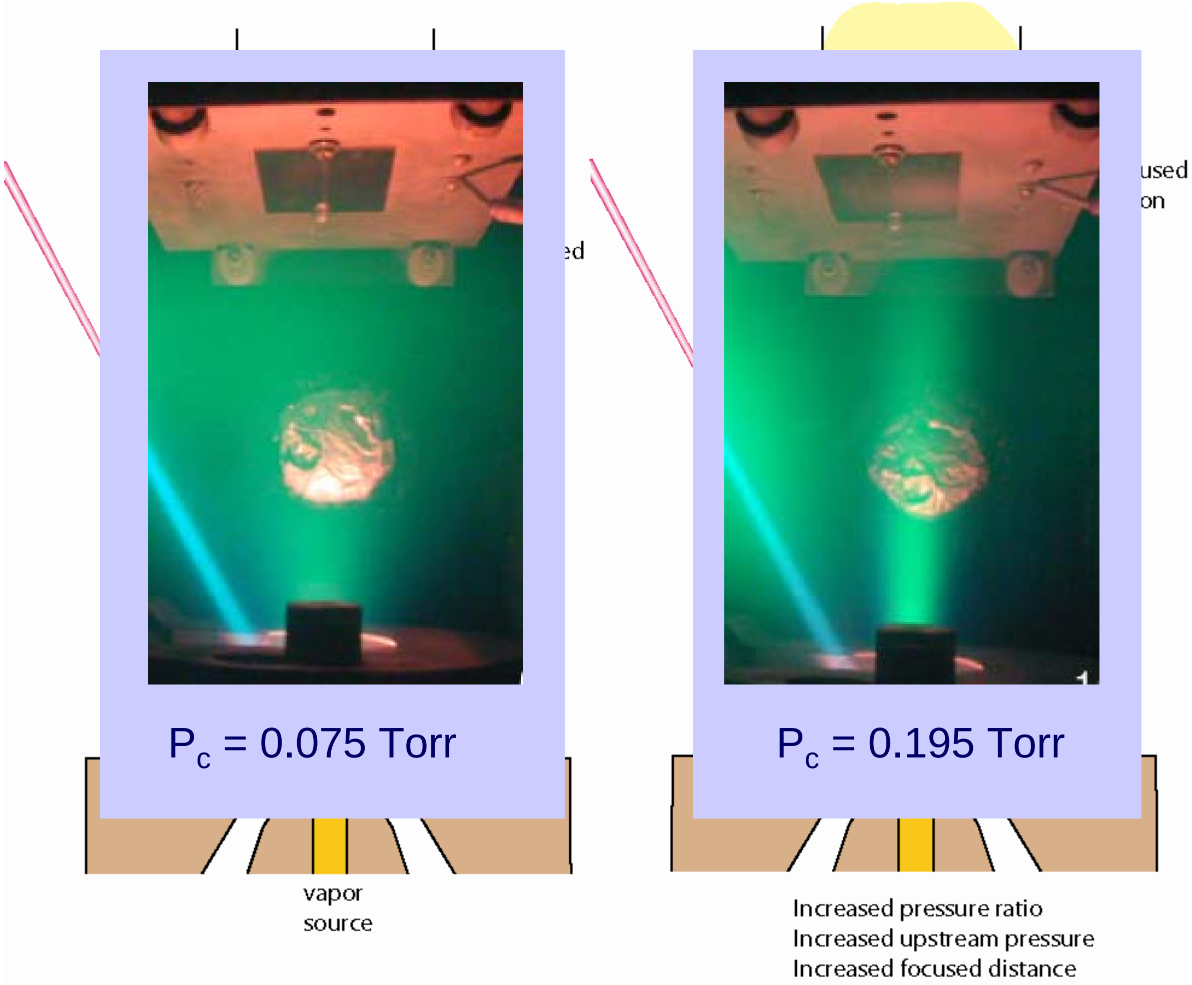
- Use supersonic gas jet to focus vapor atoms into internal regions of components
- Scatter vapor atoms onto NLOS surfaces either by controlling the speed and density of the gas jet

DVD Processing Approach for Landing Gear



Process steps required to coat the interior of a component with a material.

Internal Coatings on Tubes



De-focused region can reach different ID positions to enable control of thickness uniformity

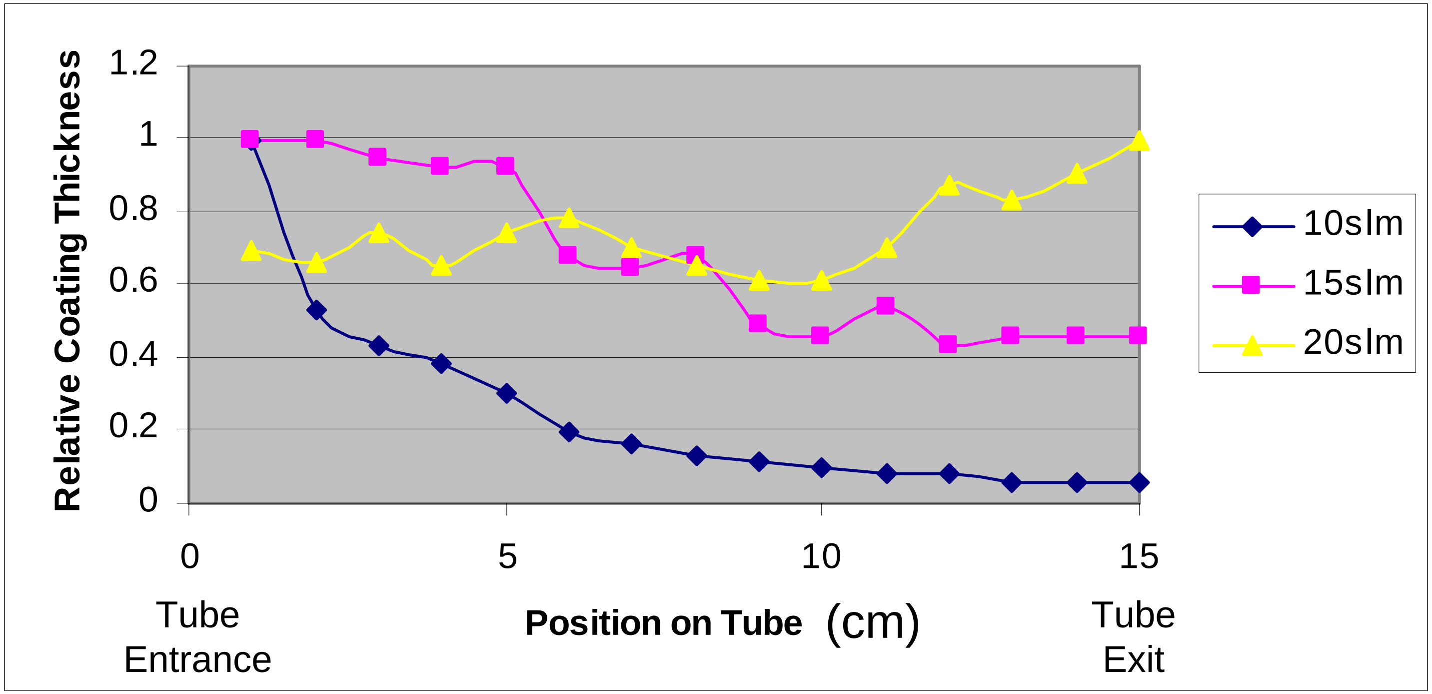
Position of de-focused region dependent on:

- -Carrier gas flow rate
- - Pressure ratio
- -Chamber pressure
- -Tube diameter
- -Nozzle geometry

Change in the location of the de-focused region of the vapor flux where NLOS deposition occurs when the gas jet pressure ratio and/or upstream pressure is increased.

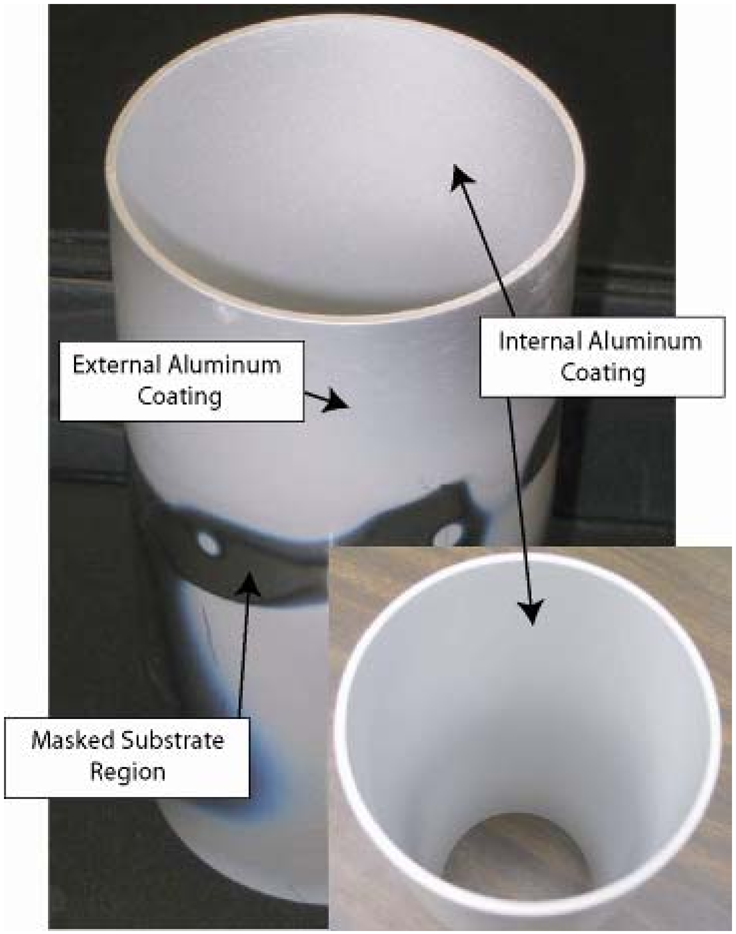
Internal Coatings on Tubes

Coating Uniformity (3"diameter tubes)



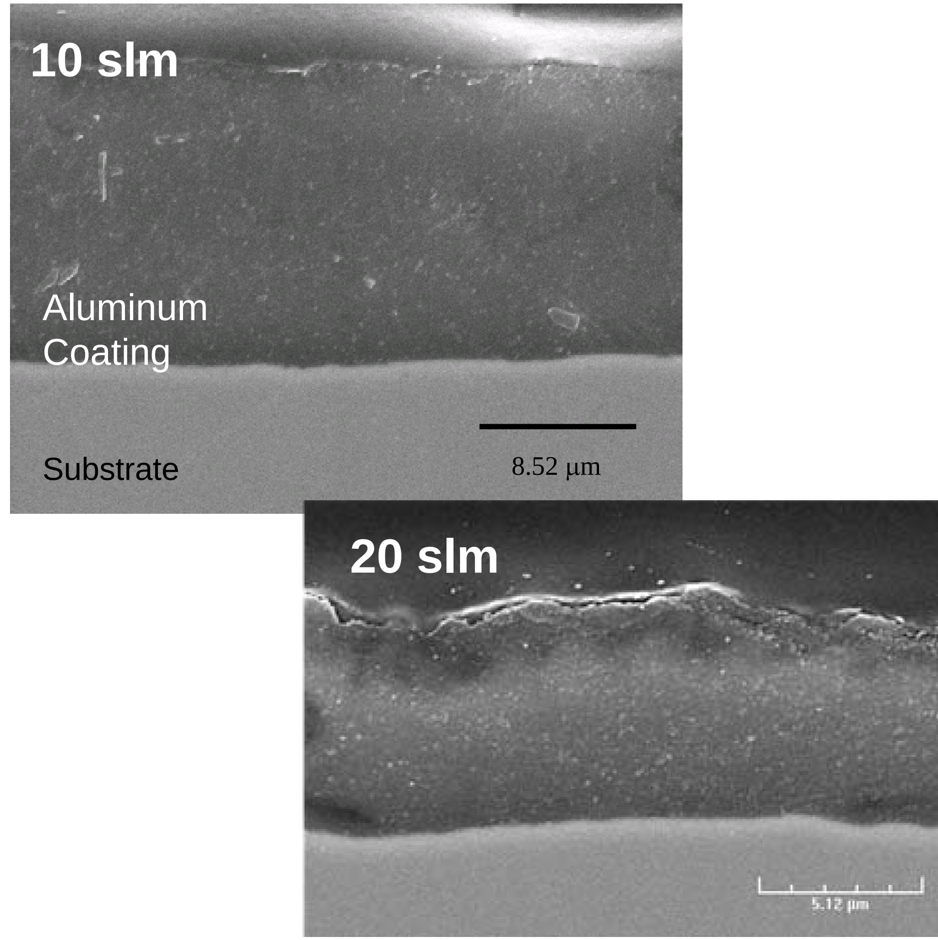
Tailor thickness uniformity by altering gas flow rate during deposition

Internal Coatings on Tubes



Substrate Temp. ~ 200ºC

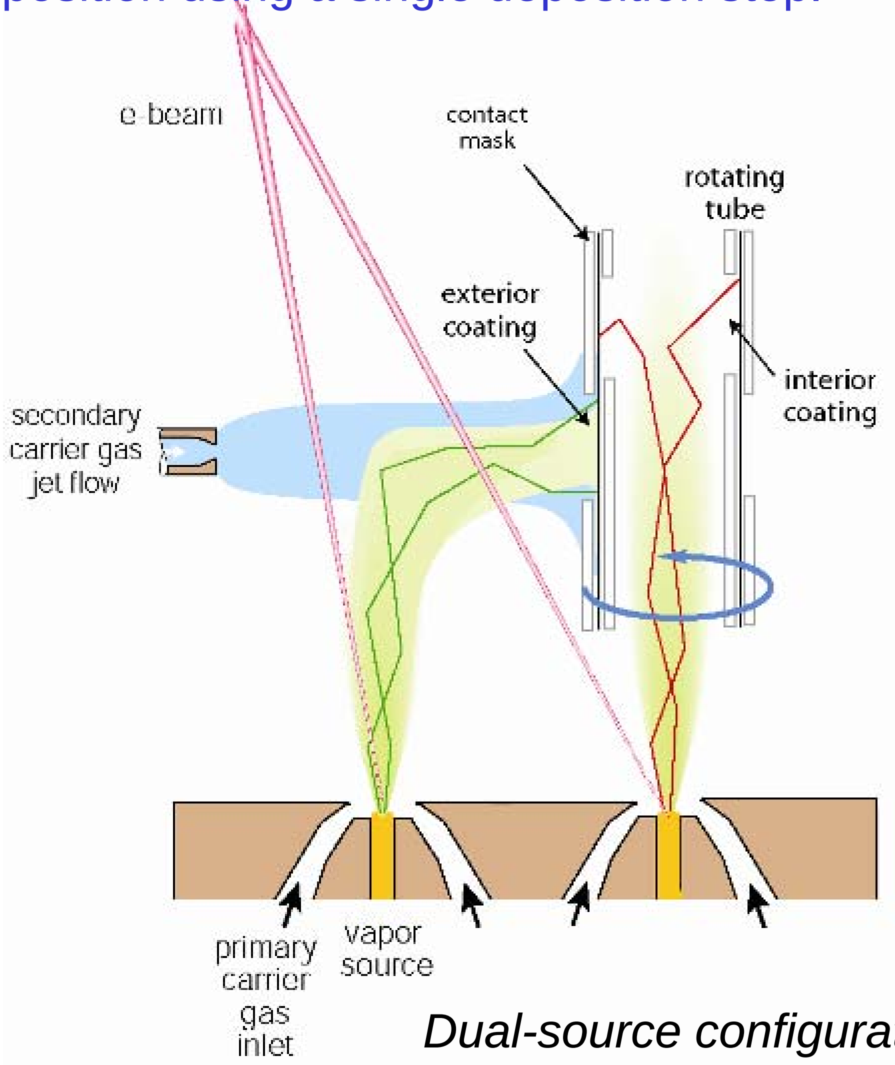
NLOS Coating Microstructure



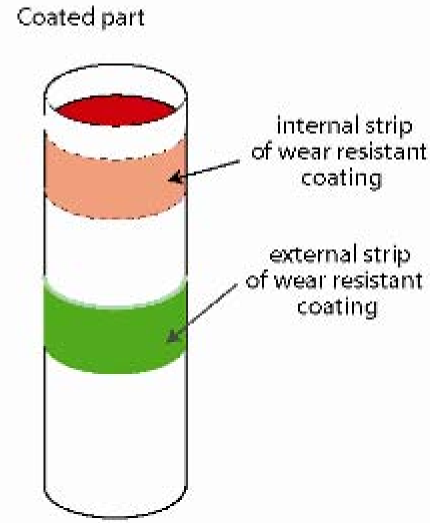
Dense Al coatings deposited at NLOS locations inside a tube

Internal / External Coating (single run)

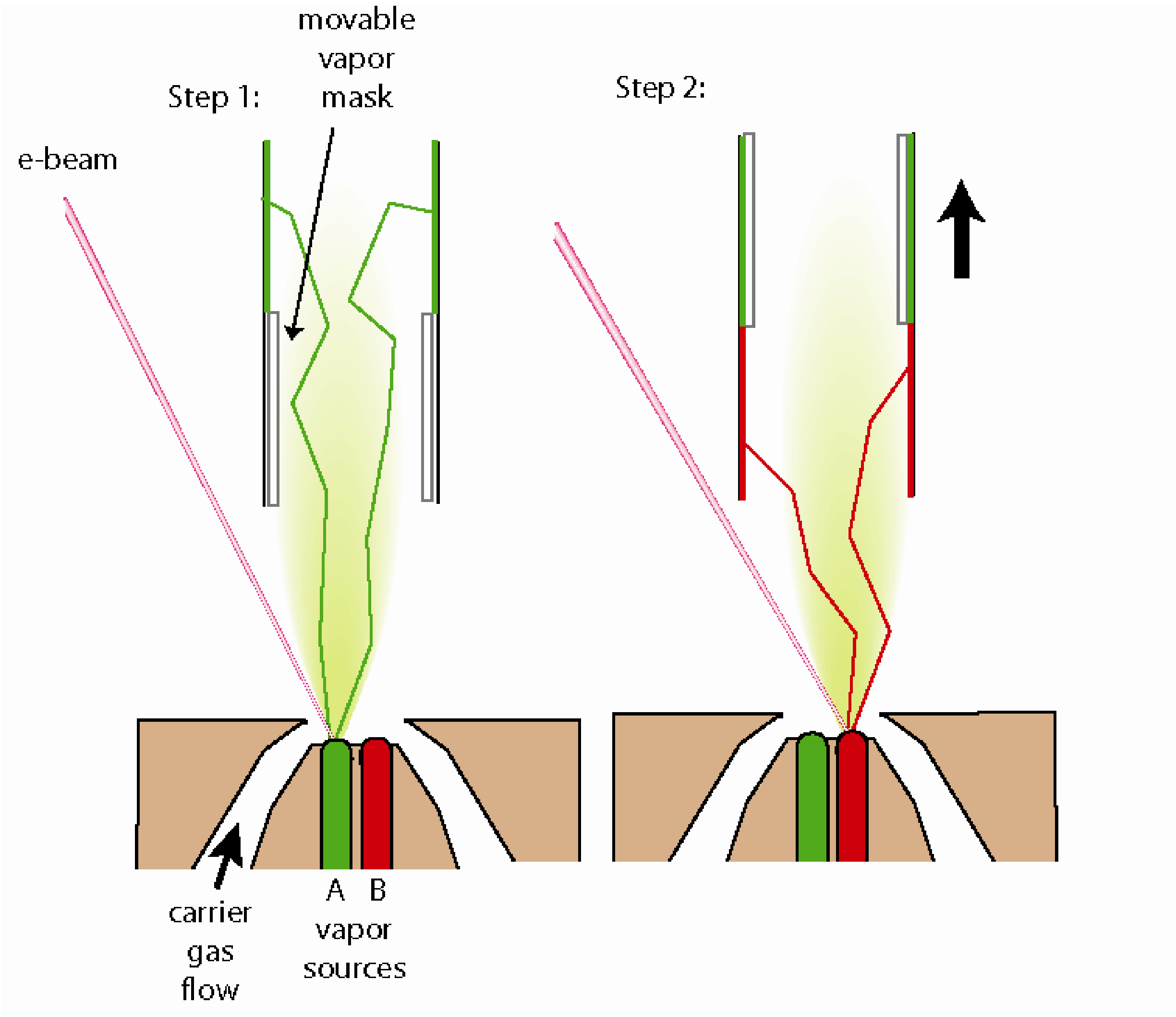
The coating of both the interior and exterior of components with a desired composition using a single deposition step.



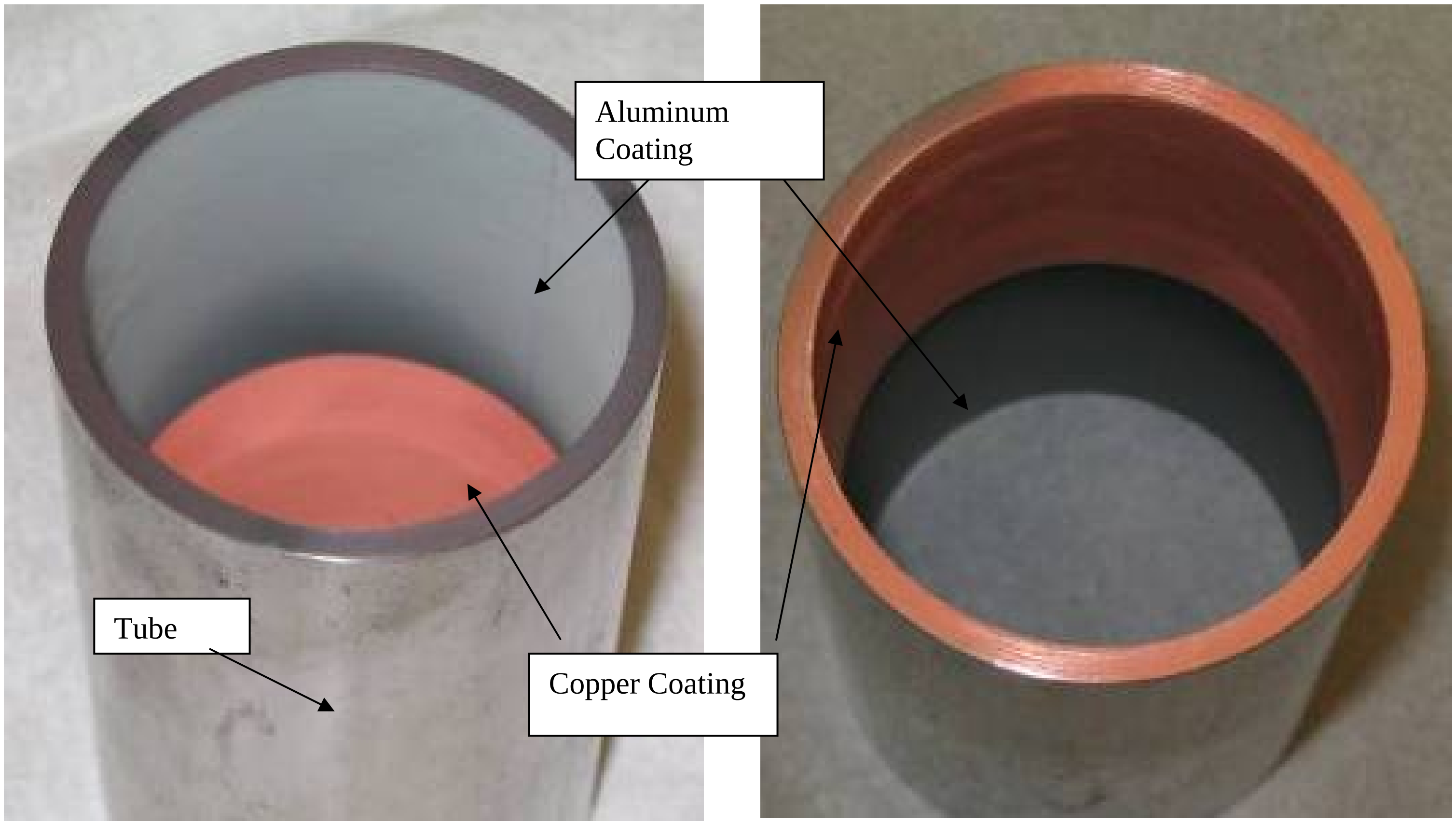
Dual-source configuration.



Controlling Compositional Distribution



Controlling Compositional Distribution



DVD Advantages for Landing Gear Coating

- Apply wear and corrosion resistant coatings onto **non line-of-sight** regions of components

- **Short** pumpdown times (10 to 15 sec); **soft vacuum** (0.1 to 0.5 Torr)

- Ability to apply both wear and corrosion resistant coatings with a single piece of equipment at high rate.
    - Potential to apply two different coating compositions in a **single deposition run**

- Ability to control the thickness uniformity on parts to **limit post-deposition grinding** steps

- Potential to deposit interior and exterior coatings simultaneously in a single processing step.

- Advanced compositional control enables the development of novel wear and corrosion resistant compositions
    - Replace current Cr and Cd coating
    - Specifically designed for use in a environmentally friendly physical vapor deposition approach.

Wear Resistant Coating Development

Wear Resistant Coatings

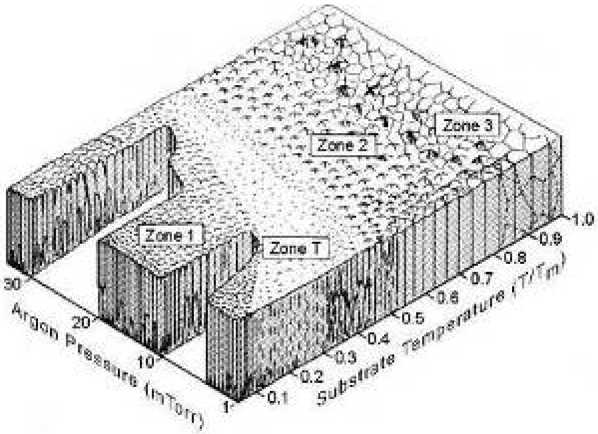
Approach *Specifically design coating composition to enable both wear performance and processability*

- Coating compositions were developed that result in nanocomposite structures consisting of nanoscaled-grains. By precisely controlling the elements in the coating and their relative volume fractions, coatings that yielded a high H/E ratio and a relatively low modulus were achieved. Such coatings are anticipated to result in excellent wear performance and good coating adhesion.

- This was achieved by creating coatings using two or more immiscible materials that can phase separate during processing resulting in nanocomposites

- Low melting point materials were used to enable good processibility (Ease of use!)

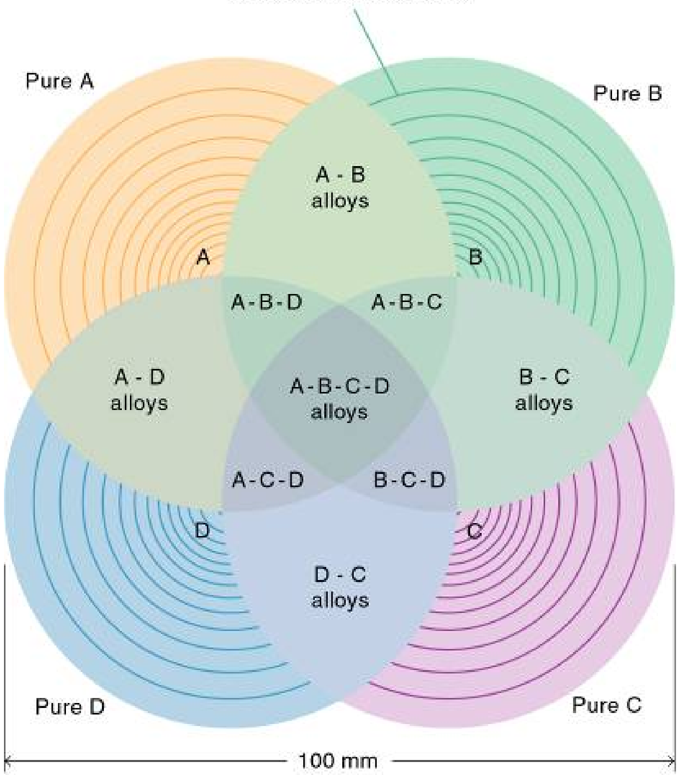
- Combinatorial study used to quickly assess potential compositions



Combinatorial Synthesis

High density / high velocity jets
lead to concentration gradients along the substrate

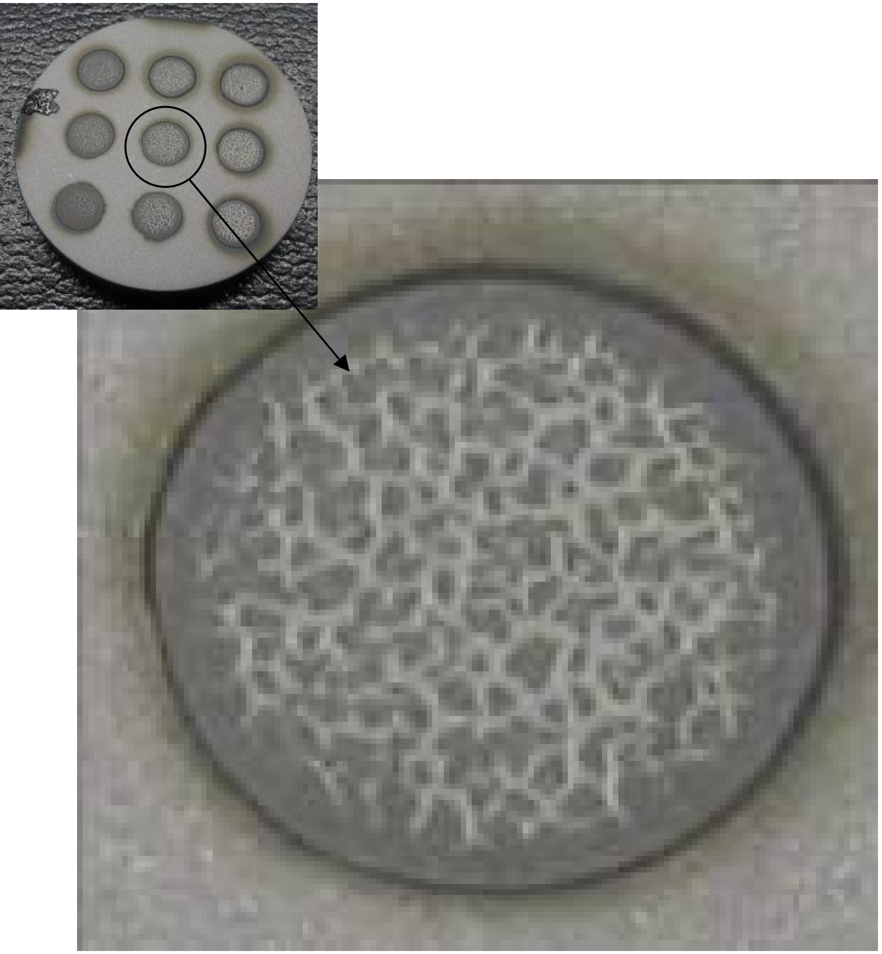
As a result individual samples containing a library of compositions can be created

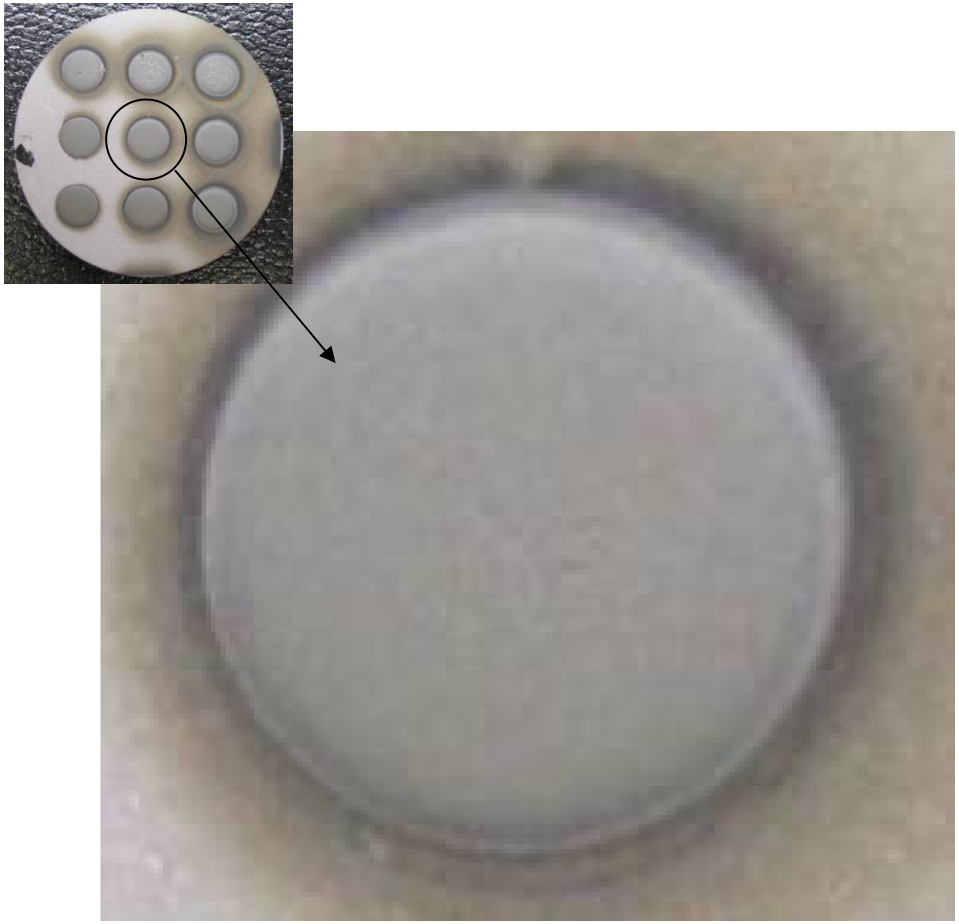


Approach can be used to accelerate the search for new coating compositions with improved properties

Nanocomposites for Wear

Two phased ternary alloys having nano-sized grains have been developed as potential replacement of hard chrome coating on landing gear





Appearance depends on position on substrate

Hardness Testing (combinatorial sample)

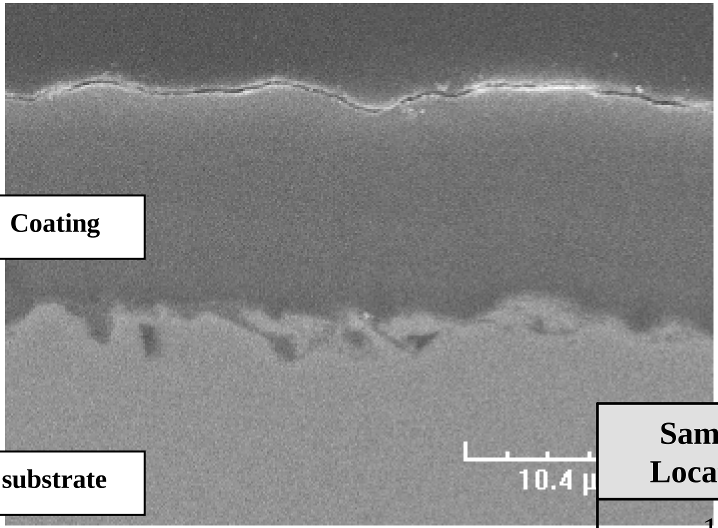
Best pixel condition:

H = 16.4 GPa
E = 83 GPa
H^3/E^2 = 0.640

Compositions of pixels of interest measured using EDS and WDS.

Hardness and Wear Testing (coupon level)

Wear Coating (coupon application)



Hardness / Modulus Testing

>3X Cr

>40X Cr

Sample Location	Hardness (GPa)	Hardness (Vickers)	Elastic Modulus (GPa)	H^3/E^2
1	33.3	3087	189	1.03
2	35.2	3178	210	0.98
3	30.0	2586	171	0.92
4	35.4	3000	193	1.19
5	26.3	2319	136	0.98

Pin-on-disc testing

	Sample Area of Wear Track [microns^2]	Sample Wear Rate [10^{-4} mm^3/Nm]
DVTI - LG031	523 ± 58	2.74
DVTI - LG029	304 ± 66	1.59
Hard Chrome	1 558 ± 218	8.16

3 to 5x reduction in wear rate over Cr

Tribological Testing (Component Level)

Battelle will test the DVD coatings with respect to metal-to-metal wear and sealing capability at a TRL 4 level

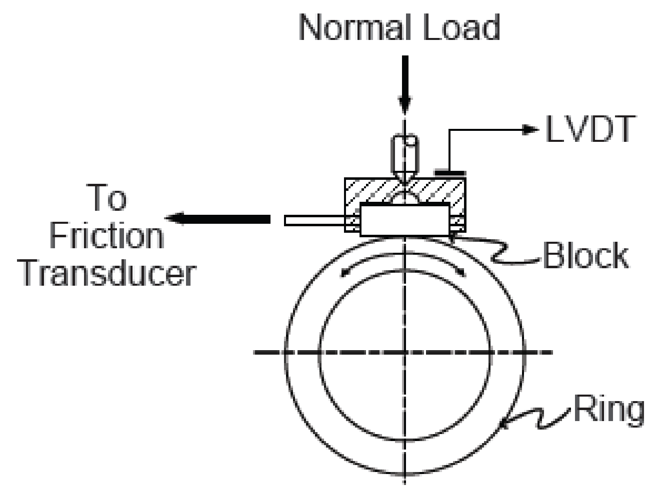
Objectives:

1) Demonstrate that the performance of DVTI-developed and deposited coatings is at least as good as that of the currently used EHC process in <u>metal-to-metal wear</u>.

2) Demonstrate that the directed vapor deposition (DVD) technique is viable for non-line-of-sight (NLOS) surfaces, where the hard chrome-alternative high velocity oxy-fuel (HVOF) process cannot be used.

3) Demonstrate that the coating is viable for sealing surfaces, where a surface finish of 8 to 12 micro-inches Ra may be required, either as-deposited, or after grinding, honing and/or polishing. It must also be demonstrated <u>that abrasion of the elastomeric seal material</u> is equivalent to, or less than that of EHC.

Tribological Testing (Component Level)



Metal-on-metal test Based on loads from a C-5 gudgeon pin

Configuration: block-on-ring 10-14° motion @ 0.75 in/s (load to be determined)

Materials: DVD OD coatings and EHC

Analysis will be optically measured size of the wear zone

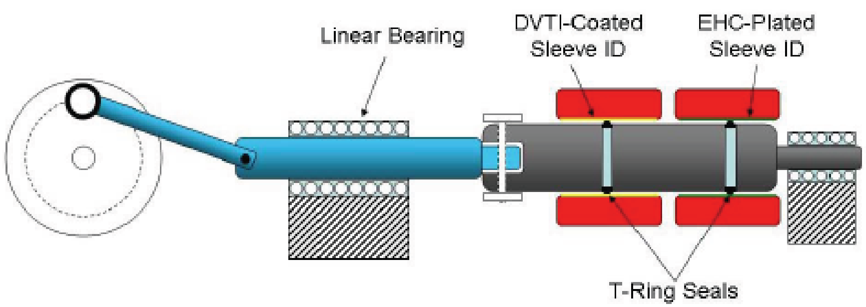
Seal wear Based on seals from the main landing gear (MLG) outer floating cylinder from the F-16

Configuration: sliding shaft with seals 1 Hz motion @ 1 in

Materials: DVD ID coatings and EHC

Seal to use will be 160 Nitrile compound rubber @ 12.8% compr.

Analysis will be wear measurements every 100-500 cycles and SEM / profilometry

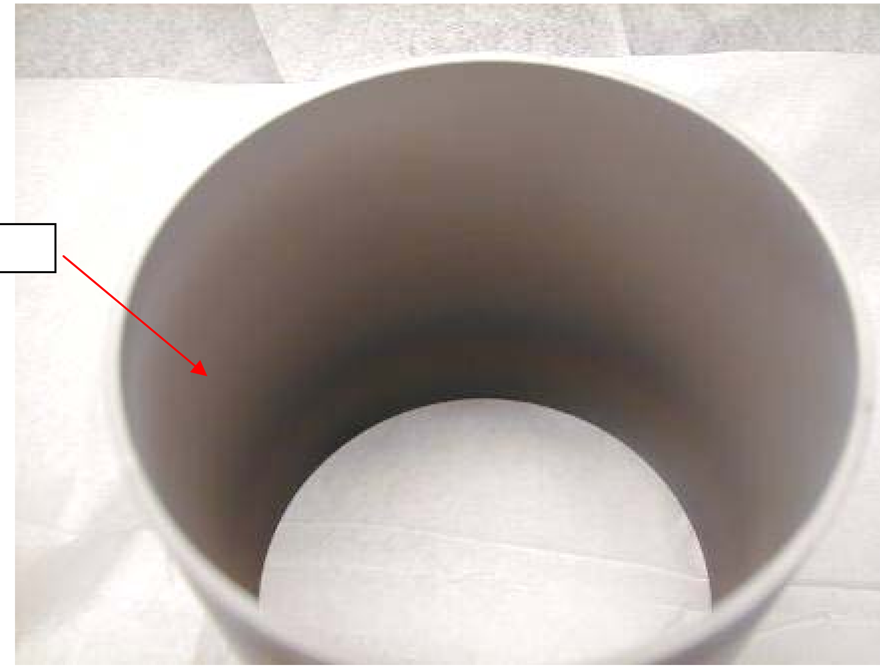


Testing Performed:
Steve Shafer – Battelle
shaffers@battelle.org

Tribological Testing (Component Level)

Wear Coating on Tubes

Coated Region

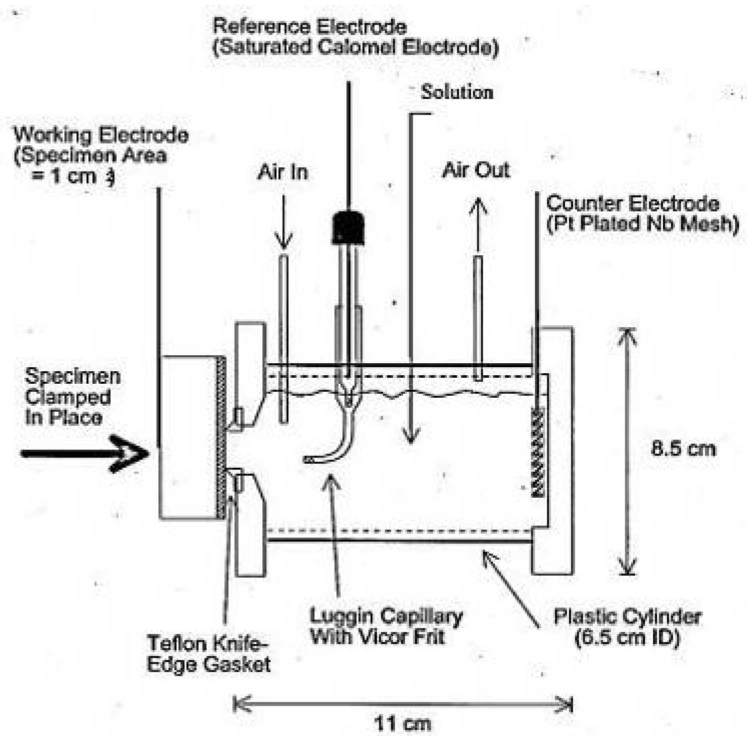


Corrosion Resistant Coating Development

Corrosion Resistant Coating Development

Development of corrosion resistant coating composition for Cadmium replacement optimized for ease of use in vapor deposition systems.

- Use combinatorial approach to develop optimized coating



Materials Selection:

- An electrochemical potential close to and below that of high strength steel (or near that of cadmium
- A relatively low melting point
- Investigating Al and Zn ternary alloys

Zero Resistance Ammetry

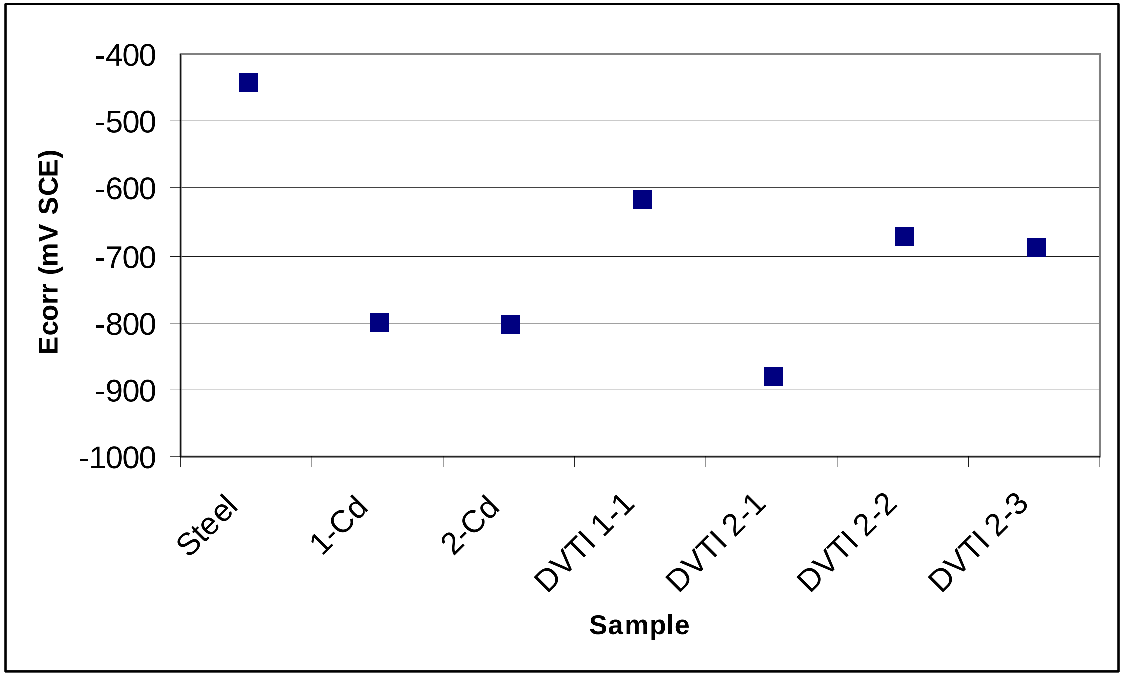
Gives the ability to accurately:

- Determine the electrochemical potential
- Determine corrosion rate

Can determine coating lifetime for a given thickness

Corrosion Resistant Coating Development

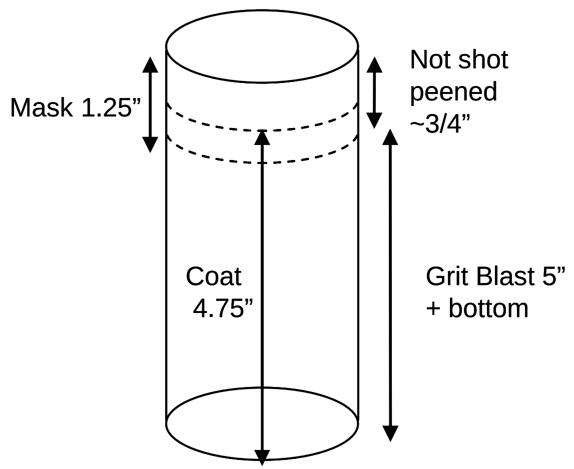
Corrosion potentials for steel substrate, Cd electroplate and DVTI coatings.



DVTI coating has a lower electrochemical potential than steel and slightly higher than Cd

Corrosion Testing (Component Level)

Testing by John Stropki @ Battelle presentation

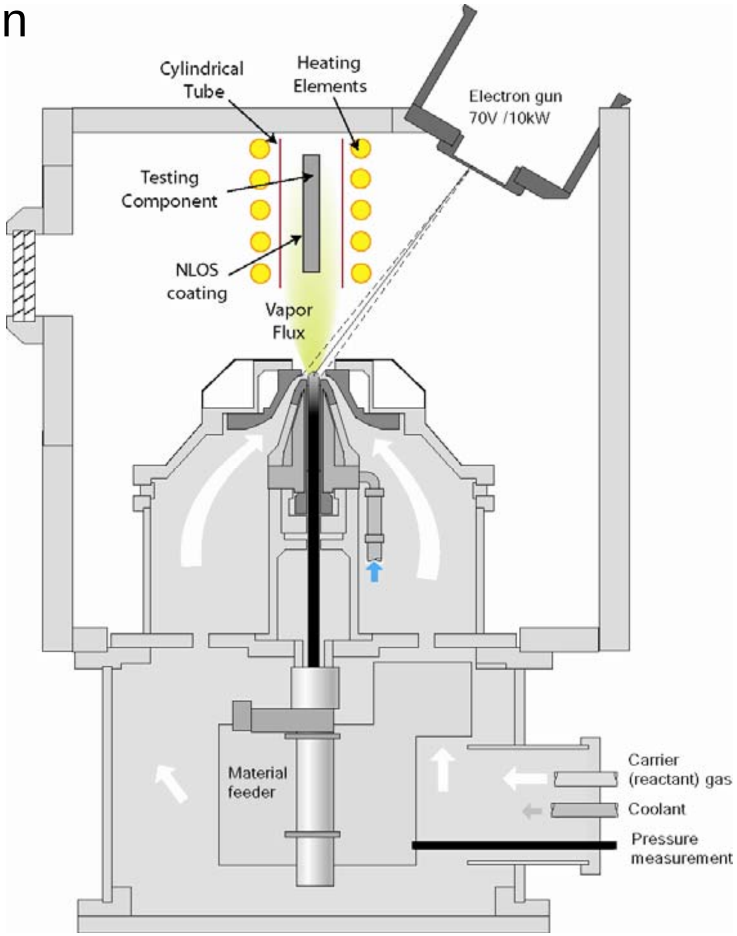


1) Test No. 1. Neutral Salt Fog Corrosion Test (ASTM -B117-94)

2) Test No. 2. General Motors (GM) 9540P/B Cyclic Corrosion Test.

3) Test No. 3. SO_2 Salt Fog Corrosion Test (ASTM G85-85)

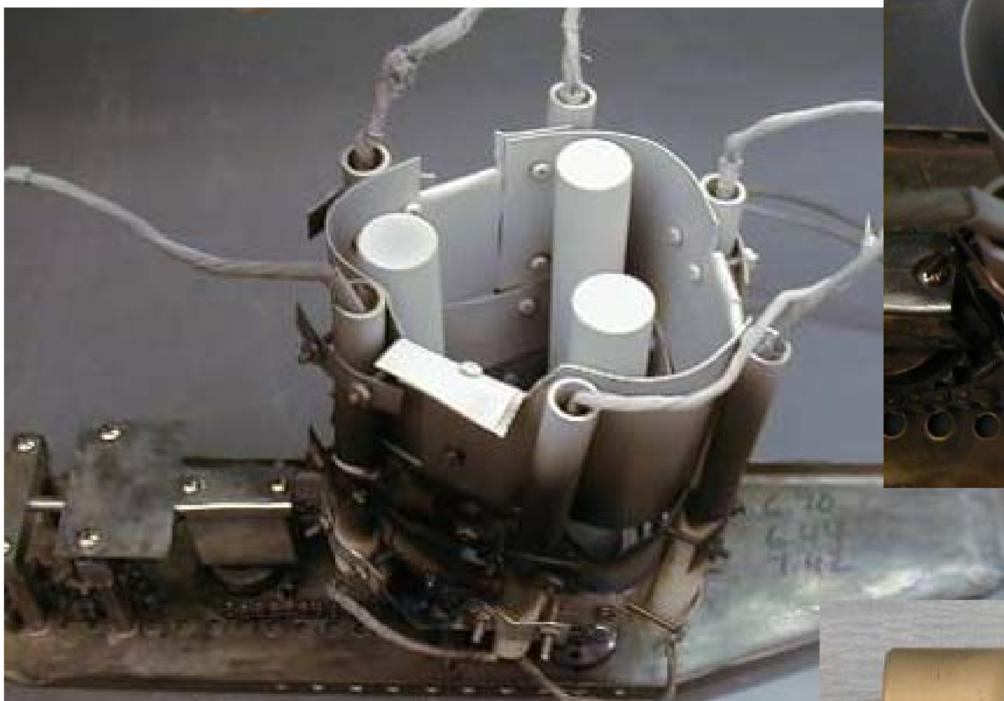
Testing in accordance with procedures and protocols referenced in Ch. 3 of the U.S. HCAT testing document

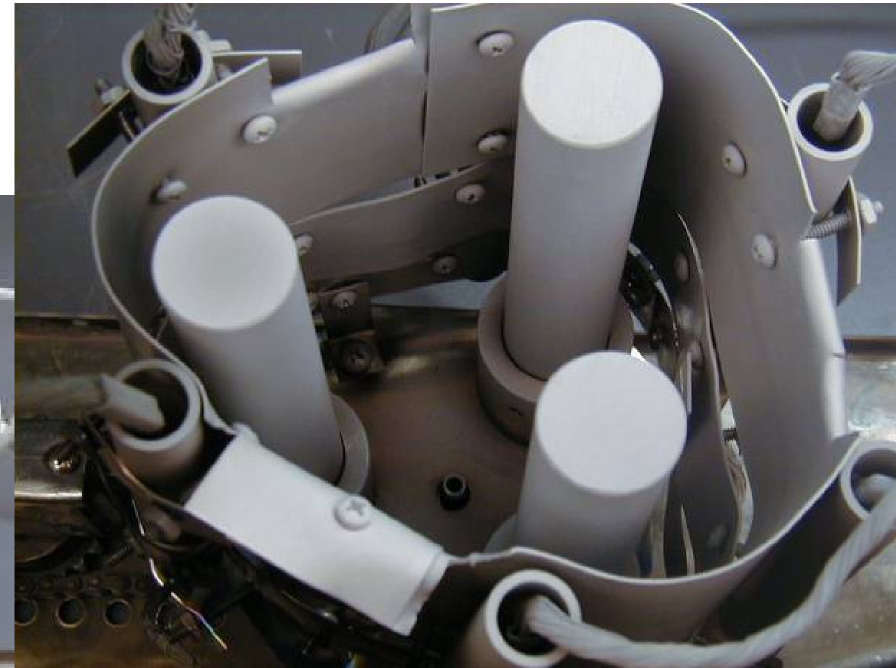


Tests to be performed by Battelle using a ATO-TECH Cyclic Corrosion Chamber

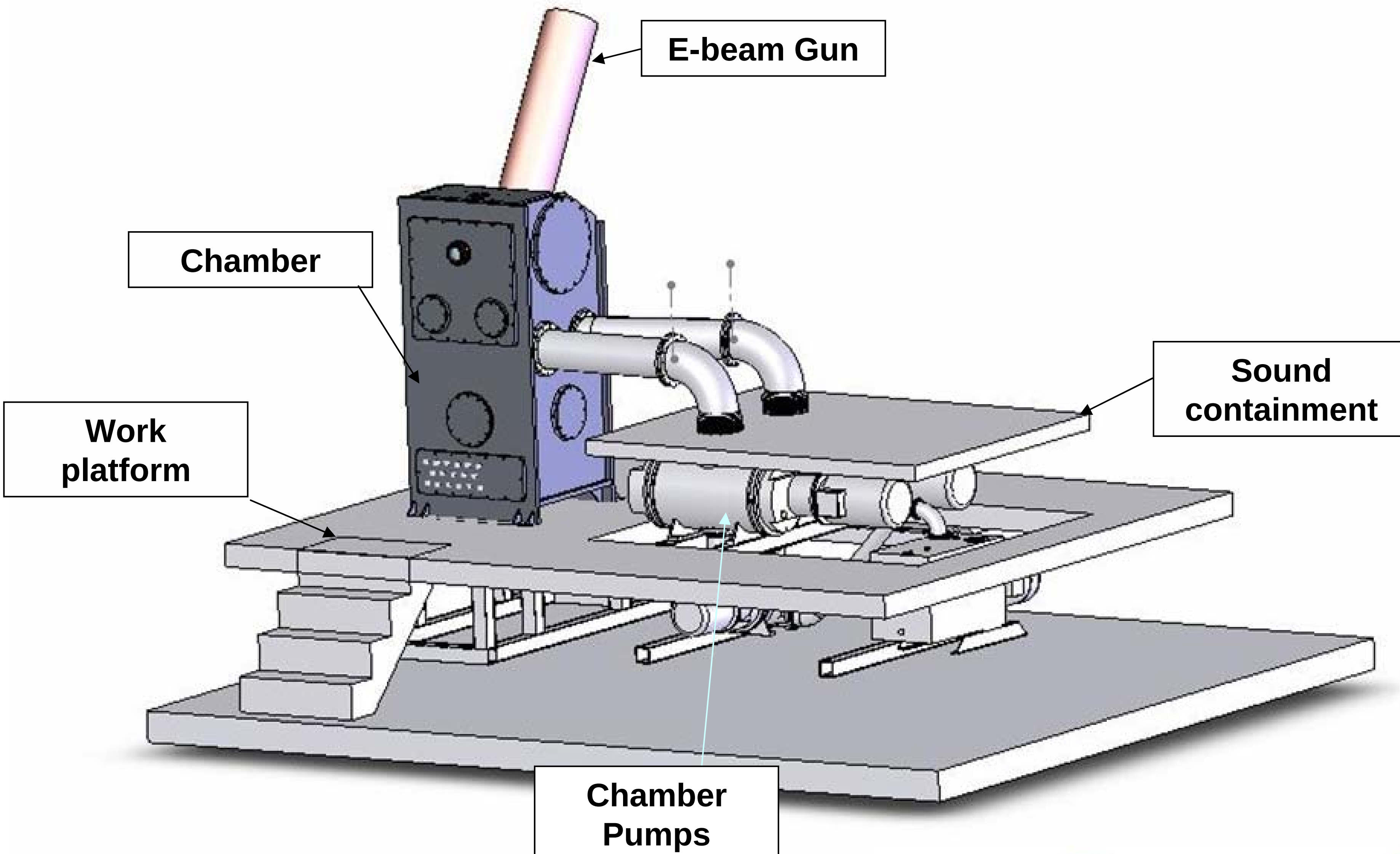
Corrosion Testing (Component Level)

Three bar heating and manipulation unit for corrosion test samples





Production Scale DVD Coater



Production Scale DVD Coater

3000 sq.ft. facility

Located in Charlottesville, VA

Questions?

Directed Vapor Technologies International, Inc.